

DISCUSSION BEFORE THE RADIO SECTION, 8TH NOVEMBER, 1950

Mr. G. Millington: I consider this to be a valuable paper because it tackles a very difficult problem in a field which has been neglected by radio engineers from the advent of long-distance short-wave communication until the recent revival of the use of long wavelengths for navigational aids. Not only does it investigate the limitations imposed on the use of such aids by the ionosphere, but it also provides information about reflection coefficients and layer heights and their dependence upon frequency, time of day and distance.

With regard to the experiments, I should like to ask whether a navigational aid could be used in the presence of errors of the type shown in Fig. 20, and whether at greater distances, where the sky wave takes precedence over the surface wave, the curves settle down again. In Figs. 25 and 26, I am intrigued by the variations of the curves at quite small distances from the transmitter, and in view of them I should hesitate to deduce from the ripples occurring further on a reflection coefficient for an interfering sky-wave.

The author does not appear to have taken into account the effect of the curvature of the ionosphere in the curves in Fig. 1, nor of the fact that, on a ray picture, the signal strength would drop to zero beyond the horizon. As the experiments show, the reflection coefficient varies with distance from the transmitter, and the actual field-strength curves will need to be constructed from these idealized ones. Such curves are shown in Dr. Bremmer's book on "Terrestrial Radio Waves," in which he discusses the random addition of the multiple reflections to give the Austin-Cohen type of transmission at great distances. It appears, however, that the conductivity of the ionosphere deduced from experimental data at long distances leads to a reflection coefficient that is too great at the shorter distances, as was pointed out by T. L. Eckersley some 25 years ago. Dr. Bremmer does not take into account the fact that energy reflected from the ionosphere must, to some extent, be diffracted beyond the horizon.

I should like to know whether any ambiguity can arise from using Fig. 3 to determine layer heights. The experimental data can often be fitted to such curves quite well in more than one position, giving rise to an uncertainty in the right choice of the height of reflection.

Finally, I am perturbed by the author's use of the term "correlation" in the definition of σ_x , although he is careful to point out how it differs from the conventional use in the comparison of signals subject to truly random variations. In Fig. 7, the term "random" is used where the process of derivation seems to be perfectly definite for an assumed geometrical situation.

Group-Captain E. Fennessy: The paper is of very great interest as an attempt to introduce facts into a field in which opinions have reigned supreme for far too long. This tendency has been particularly marked at the series of civil air conferences held during the past four years. While still leaving much to be measured and assessed, the paper is a major contribution to the evaluation of navigational aids whose performance is affected

by the behaviour of the ionosphere. The results put forward have not been obtained by laboratory measurement or by calculation, but by extremely long and often hazardous flights in all weathers and over wide areas of land and sea; I know that the author has flown as far south as the Sahara, west to beyond the Azores and northwards beyond Iceland, and the results and data now placed before us are the outcome of these flights. Anybody who has had any experience of this type of work will know the very great strain that accurate collection of scientific data while flying at high altitudes and for long hours can produce.

While, on the present evidence, there appears to be a good case for assuming that the band between 80 and 120 kc/s is the optimum one for navigational aids of the medium-range type, there is nevertheless very little information on the true behaviour of frequencies at the very bottom of the long-wave band, i.e. below 20 kc/s. In view of the fact that, at the present moment, there is no true system of long-range navigation which meets the requirements of the aviator, it is worth while giving more attention to the very low frequencies of the radio spectrum, since it remains the only portion of the spectrum in which we may find a solution to the long-range navigational-aid problem for any system relying on transmissions from ground stations.

Mr. H. E. Hogben: Although a large mass of data on sky-wave errors has been accumulated in the last few years, it is still not enough for an adequate check of the theory set forth in the paper. Nevertheless, curves of random distance-error prepared by the Admiralty Signal and Radar Establishment from observations made in His Majesty's ships show the same general form as the author's theoretical curves.

Last year, measurements of day-time field strengths of Decca transmissions at various ranges were made by A.S.R.E., from which the effective height of the ionosphere in autumn at the various frequencies of the Decca navigation system (70–127 kc/s band) was deduced from the range of grazing incidence. The method appears to be more accurate than that used by the author. Values of about 70 km were obtained, which are in substantial agreement with the author's results.

I support the author's view on the question of the possible use of frequencies below 80 kc/s for an aid to long-range navigation. I think that the technical prospects of the lower frequencies are discouraging. It is true that at long ranges there appears to be a stable sky-wave pattern which, if related to local geographical co-ordinates, might give a useful radio-navigation system, but this appears to be equally the case at 100 kc/s, where the difficulty of getting adequate signal/noise ratio at long range is less. I do not think that there is any evidence that the sky-wave pattern at long ranges is any more stable at frequencies below 80 kc/s than it is at the frequencies which have been chosen as the optimum for long-range navigational aids.

Mr. W. Ross: I am interested in what happens beyond the horizon. The curves shown in Fig. 1 ignore the horizon so far

as the sky waves are concerned, but there is great interest in just what happens there. I understand that considerable advances have now been made in this problem, but I am not sure that the complete answer is yet known.

A first approximation would be to say that at the horizon the sky-wave field drops to zero perpendicularly (see Fig. 1). One is tempted to say that there may be a region in which the ground wave is predominant followed by one in which the sky wave is predominant and then a further region in which the ground wave takes control once more. If one examines the question a little more deeply one finds that there must be some rounding off at the point where the field strength begins to fall, because the reflection of the waves at the ground surface undergoes a change when grazing incidence is approached. Further, the sky wave itself must suffer diffraction around the earth, and—as I believe has now been shown—there must also be some focusing effect at near-grazing incidence on the ionosphere. It therefore seems that, although the sky-wave intensity will fall for points beyond the horizon, it will not fall so precipitously as might first appear to be possible. I should like to know whether the fall takes place in such a way as to leave the sky wave or the ground wave predominant.

As the curves of Figs. 27–30 show, there is a somewhat profound difference between the day and night performance of the Decca system examined at long ranges; there is greater stability during the day than during the night. That can be explained even if the day-time signals at these long distances are due to sky waves, although at first sight I believe that the thesis is not proven; the signals at long distances might possibly be those due to the ground wave. The Figures do not give absolute values of field strength, but from information given to me privately by the author, I have concluded that the day-time signal strength at these long ranges is not inconsistent with expected ground-wave levels.

Dr. H. G. Hopkins: I should like to comment on the measurement of reflection coefficient. As the term is generally used, “reflection coefficient” refers to the relation between the incident and reflected fields, with particular attention to a specified polarization component; thus, generally speaking, we are concerned with a magnitude and a phase angle. In the experiments described in the paper, no precautions seem to have been taken at the receiving end to isolate one particular component. Indeed, as Fig. 20 shows, there is a difference between the two aerials which have been used, and that difference is attributed to some differing selective action with respect to the components of the ionospheric wave.

The interesting point is that the reflection coefficients measured under more or less identical geometrical conditions on the two aerials have about the same value. Does this arise because some allowance has been made for the pick-up properties of the two aerials? That, however, would seem to be a difficult undertaking, since one would expect the pick-up properties to depend not only on the angle of incidence but probably on the aspect of the aircraft (i.e. its direction of flight) and also on the state of polarization of the wave. I should welcome any information which would make it possible to define more closely the ionospheric property measured, and which is connoted in the description of the experiments by the term “reflection coefficient.”

It is mentioned in the paper that at long ranges there is a 180° phase-change on reflection. That is a tentative suggestion, but I assume that this reference is to the pick-up of the vertically polarized component. It would be helpful to know how the phase change was measured. Can the author say how this quantity varies with distance, frequency, time of day, etc.?

Mr. W. Struszynski: With reference to Fig. 3 of the paper, it is interesting to note that curves for large distances bend

gradually to the horizontal, so that for a given effective height of the ionosphere the rate of change of path difference with distance becomes small (see also Fig. 4). From this it follows also that, for relatively large changes in height, there are small changes in path difference. It therefore seems that it would be possible to use low-frequency systems such as the Decca Navigator for long-range navigation in day-time in the region where sky wave predominates. This would resemble the use of Loran, which works almost entirely on reflected waves. Decca charts for this range should be computed for the length of the sky-wave path, assuming an average height for the ionosphere, instead of taking distance measured along the surface of the earth. For frequencies used in the Decca system, this region would lie between 1 300 km (since the equality of sky and ground waves occurs at about 1 000 km) and 1 800 km, i.e. the distance at which tangential incidence occurs. It is not clear what happens when this range is exceeded, but it might also be possible to extend the range even further, so that the signal/noise ratio alone would be the limiting factor. The inconvenience of such a method of navigation would be that the area of ground wave coverage would be separated from that of sky-wave coverage by an area where the navigational system would not work at all.

Mr. Ross asks what happens at tangential incidence of the sky wave. Some experiments were carried out at A.S.R.E. in this connection, and the field intensity of Decca transmissions was measured at long ranges. Although the results obtained are incomplete from a scientific point of view, they do bring out some interesting points. There appears to be a possibility of measurement of the effective height of the ionosphere on low frequencies by determining the distance corresponding to tangential incidence of the sky wave. At the grazing incidence, a considerable reinforcement of sky-wave field occurs, owing to the focusing effect of the concave ionosphere. Then a sudden drop of sky-wave field-strength follows when tangential incidence is reached, i.e. when the angle becomes smaller than the Brewster angle. The effect is more pronounced on lower frequencies of the band (i.e. 85 kc/s) than on higher frequencies (i.e. 127.5 kc/s). This variation with frequency can be explained by assuming a non-uniformity of the ionosphere which would have a maximum effect at higher frequencies, so that, in fact, there would be practically no reinforcement of sky wave.

Mr. H. Stanesby: I am interested in the lane shifts shown in Fig. 27. The author confesses that he cannot understand why he gets shifts in one direction at sunset and no corresponding changes in the opposite direction at sunrise. It is true that at sunset the ionosphere rises, but it does not necessarily follow that the ionosphere falls again at sunrise in such a way that the diurnal cycle is symmetrical about midnight. Nature does not always do things in that symmetrical way; for example, water comes down from the sky in the form of rain, but it does not go up again in that form, although the rain reappears in the sky later, and sometimes all too soon.

It appears that at sunset the ionosphere rises smoothly as a result of the normal recombination process, and this gives rise to Doppler effect on the transmission from the Decca master station and a slightly different amount of Doppler effect on the transmission from a slave station. The difference leads to a shift in the corresponding lane in one particular direction, which will be registered on the Decca instrument. However, I suggest that when the sun rises the ionosphere may not fall smoothly and that the ionization may reappear directly at a lower level; in other words, although the layer rises smoothly it may come down discontinuously. If this discontinuous change of height gives rise to a discontinuous change in phase corresponding to more than one-half of a lane, the corresponding lane shift will not be

correctly registered on the instrument and the change in instrument reading at sunrise will not be the reverse of the change at sunset.

The author states that the instrumental accuracy of a navigational system increases in direct proportion to the base-line distance. Does he mean that, for a given differential time-error, the resulting error in a position line is inversely proportional to the base-line length? If this is so, I feel that the expression "instrumental accuracy" is somewhat misleading. The author's conclusion that the effect of random time-errors is reduced by using as long a base line as possible is very important. It would appear, in fact, that the inaccuracies due to these time errors vary inversely as the square root of the base line, which is, I believe, the first time that this has been demonstrated.

Dr. R. L. Smith-Rose: I should like to make one or two remarks of a general nature, partly, I think, in defence of the author against one or two of the earlier speakers. Personally, I like the title of the paper, because I regard it as just as much a contribution to our knowledge of the propagation of waves by way of the ionosphere as a means of improving our knowledge of the characteristics of certain navigational aids.

The situation with which the author seems to have been confronted was that those responsible for exploiting certain navigational aids which had been developed in the last decade asked what performance they could expect of these aids under specific conditions. The answer must have been rather depressing, because they would be told that for the past 20 years (Hollingworth's almost classic experiment was carried out 25 years ago) very little attention has been given to understanding or finding out the characteristics and behaviour of the ionosphere at these low frequencies. Furthermore, although it is known that, under high-frequency conditions, the ionosphere varies with the season and time of day and in different parts of the world, we do not know how to extrapolate our knowledge from high frequencies to low ones.

In the face of that somewhat gloomy situation, the author is to be congratulated for having the courage not to be satisfied with that position and for adopting a more direct approach in tackling the problem. He has taken certain suitable values for the height of the ionosphere and given it reasonable values of reflection coefficient, by day and by night; he has then worked out what result is to be expected at various distances from a transmitting system and has made measurements in an aeroplane to see how these line up with the expectations.

I think that all of us must sympathize with anyone who tries to take quantitative measurements in an aeroplane, particularly when he has to compare the results with his calculations. As the aeroplane flies along, the investigator is dealing with waves reflected from different points in the ionosphere, which probably have quite different characteristics and are, in any case, changing continuously as the aircraft proceeds.

Some speakers have complained that the author has not deduced enough knowledge about the ionosphere from his results. I think that this is possibly true, and I hope that the author will be encouraged to go on with his investigations and do more correlation of the experimental results with his calculations. We should all like to see the additional types of measurement for which some speakers have asked, such as those of polarization and phase difference, but this would have taken more time.

We ought to be grateful to the author for writing up his results at a reasonable stage of the investigation, for too many research workers go on too long with their work before publishing it. I hope that the author will go on with his work and also encourage others who can adapt their own techniques to provide

more knowledge of wave propagation by way of the ionosphere, which is needed to help those who are responsible for exploiting this and other types of navigational aid.

Dr. J. S. McPetrie: I think that Dr. Smith-Rose's remarks are most appropriate, particularly as the paper reminded me of a much earlier paper by Smith-Rose and Barfield* on the first type of radio-navigational aid, the radio direction-finder. They investigated very systematically the errors in bearing found in direction-finders and, in order to explain their results, they postulated the existence of the ionosphere, a hypothesis which was shortly afterwards verified by the classic experiments of Appleton and Barnett. In the present paper, dealing with the performance of modern types of radio-navigational aids, the author has been able to deduce values for the day and night heights of the ionosphere which are remarkably close to those derived by other methods.

Mr. T. Kilvington: I should like to discuss briefly the matter of phase change on reflection from the ionosphere. The author has suggested that there may be a phase change of 180° and says that this is not significant in the derivation of layer height. It will, however, have an important effect on phase measurements in some cases. In a system employing two signals of the same frequency, if each of them is changed by 180° the phase difference between them will not be altered. However, in the Decca system, where two different frequencies are transmitted, a 180° phase-change represents a different time for each frequency and when the two frequencies are multiplied up, one by an odd and the other by an even number, an error of one-half of the period of the comparison frequency will be obtained in the time measurement.

That same error, corresponding to one-half of a lane, should be apparent if the result obtained with a vertical-rod aerial mounted on top of the aircraft is compared with that obtained using a vertical rod below the aircraft. Perhaps the author would confirm this.

If one of the signals is received by reflection and the other by ground-wave transmission, then the error in time due to the phase change on reflection will be half a period of the reflected-signal frequency and not of the comparison frequency. This amounts to $4\frac{1}{2}$ microsec for the higher frequency in the case illustrated in Fig. 20, and is quite a substantial proportion of the variation recorded.

A point that I find somewhat puzzling is the difference in sign of some of the time errors in Figs. 20 and 21. I should have expected that errors due to ionospheric reflection would always tend to decrease the time difference measured along the projection of the line joining the transmitters. Therefore I wonder whether some of the variations may be due to integration errors, and I should like to know whether any resolution of ambiguity was attempted during the periods when there were large deviations.

Dr. B. G. Pressey: Referring to Figs. 23 and 24, the author points out that during the first part of the flight—up to a distance of 300 km—the predominant wave received is the ground wave, while, just at the point where the aircraft crosses the coast, there is a small, but marked, local phase-disturbance. There is little detailed knowledge available concerning the changes of phase which occur when a wave crosses a discontinuity such as a coast-line. However, it would be expected that the phase changes at the coast would be local ones and that they would diminish with the height of the aircraft. It would therefore be of interest if the author could give the approximate height at which the aircraft crossed the coast and, if possible, at other points on the route.

* SMITH-ROSE, R. L., and BARFIELD, R. H.: "The Cause and Elimination of Night Errors in Radio Direction-Finding," *Journal I.E.E.*, 1926, 64, p. 831.

Major W. V. G. Fuge (*communicated*): With reference to the effect of the ionosphere on the amplitude of signals received at sunset and dawn, my experience in the tropics has been that the variations in amplitude which occur at these periods are similar and take place in reverse order. There is no appreciable twilight in the tropics. For about fifteen to twenty minutes before sunset, signals from distant stations increase steadily in strength. For about fifteen to twenty minutes after dawn, they fall off steadily in strength. The rate of increase just before sunset appears to be about the same as the rate of falling off just after dawn.

Mr. W. T. Sanderson (*communicated*): The paper is extremely valuable as the first attempt to reduce to some pattern the confusion of data, fable and opinions now prevalent about long-range radio navigational aids. Those who have been engaged on kindred studies will appreciate the great amount of thought and work which the author has devoted to it, and it is significant that he has refrained from suggesting yet another system—"Caradux" possibly—to add to the multitude of types which have been proposed, although it would be interesting to know whether he has anything specific in mind. The author implies that a c.w. type of hyperbolic aid should be used in the 90–110-kc/s band and considers that the base-line length is conditioned by ambiguity considerations. The last conclusion seems debatable. In c.w. systems, at any ranges where the sky wave may be about equal to ground wave, there appears to be no means of resolving the cycle or lane ambiguities, and such systems essentially provide a way of determining the change of position from some starting point known by other means. This must be reckoned a disadvantage, but by no means such a serious one as it is frequently made out to be. Two examples of widely used navigational aids which depend on integration and incorporate in themselves no means of resolving their "ambiguities" are the clock and the ship's log. The requirement of integrating-

type aids is that they should enable a change of position to be determined with the greatest possible accuracy.

Owing to the accuracy-reduction factor involved in all time-difference measuring devices, I conclude from Fig. 12 that, in general, ambiguities do not enter into a decision on base-line length, but the wider the spacing between stations the better the accuracy—subject to a criterion of the form that the lane width multiplied by the chance of miscount in a transition from ground-wave to sky-wave control should be a minimum.

A new aid can be justified if the position information is either more accurate or more rapidly obtained than it has been by existing means. For very-fast-moving aircraft, speed of presentation is essential, and c.w. systems have the great advantage that the incoming signals can be immediately converted into a map display and hence the indicated track of the aircraft shown as a trace.

This arrangement offers a further valuable feature in that the σ_x and σ_t terms in eqn. (7) can be materially reduced. As the point of observation is moving rapidly, the σ_x term can also be regarded as a function of time. The importance of the σ_t term depends on its time-constant, i.e. the period that must elapse between two readings which may be regarded as independent. If this were a fraction of a second, the resulting errors could be eliminated by introducing inertia into the display, and short- and medium-range aids would be virtually error-free. With the actual values of time-constant for the combined σ_t and σ_x terms in fast-moving aircraft, the trace display should enable the effects of the random errors to be minimized by visual estimation of the mean track through the oscillatory trace recorded.

So many factors enter in the problem that, although at present the indications are that the 90–110-kc band is well chosen, it may yet prove desirable, as Group-Captain Fennessy suggests, to examine more closely the possibilities of the use of very low frequencies.